

PATENT

File No. 12350.0008.000000

**APPLICATION FOR UNITED STATES LETTERS PATENT**

**for**

**NONABRASIVE MEDIA WITH ACCELERATED CHEMISTRY**

**by**

**Jerry Holland, Mark Michaud, Michael Salerno  
Gary Sroka, and Lane Winkelmann**

**EXPRESS MAIL MAILING LABEL**

NUMBER EL018591952US  
DATE OF DEPOSIT 01/10/01

I hereby certify that this paper or fee is being deposited with the United States Postal Service  
"EXPRESS MAIL POST OFFICE TO ADDRESSEE" service under 37 C.F.R. 1.10 on the date  
indicated above and is addressed to: Commissioner for Patents, Washington D.C. 20231.

*Maria L. Alvarez*

Signature

## BACKGROUND OF THE INVENTION

This invention refines the surfaces of metal articles for cosmetic purposes and/or for mechanical functioning purposes, so that the surface of those articles is isotropic, superfinished, and of specular brightness. This invention encompasses both a method for refining these surfaces, and the novel articles that result from the practice of that method. The improved surfaces produced by this invention may yield improved performance in the parts processed.

There are a variety of metal articles for which machining/grind lines are a problem. Examples of mechanical parts with critical working surfaces include splines, crankshafts, camshafts, bearings, gears, couplings, and journals. For these parts, poor surface contact performance caused by lines can increase friction, torque, noise, vibration, operating temperature, and impair lubricity, and negatively impact failure in areas of wear, scuffing, plastic deformation, and contact fatigue and/or bending fatigue. For gears or other parts placed in a demanding environment such as the drivetrain of a helicopter or racing car, resistance to these types of failures in effect defines the useful life of the article.

Critical surfaces (including recessed areas) have conventionally been refined through various machine grinding/polishing processes. But those processes have multiple drawbacks. For complex shapes, machine grinding tools are very expensive, require skilled operators, and undergo excessive wear. Metal parts having an HRC of approximately 42 and higher are not well suited for these techniques. Machine grinding often leads to directional grind lines, and can damage the heat treatment of a metal surface, creating potential failure sites. Finally, machine grinding is carried out on a part-by-part basis, and as such, is plagued with problems of repeatability and uniformity.

REM Chemicals, Inc. has developed and described in its patents techniques that refine metal parts, on a mass process basis, to a smooth and shiny surface. Those techniques have been used commercially for many years in which the process objective is directed primarily to the cosmetic appearance of the part rather than to its mechanical performance. To that end, REM's U.S. Patent No. 4,491,500 discloses an improvement to traditional mass finishing methods, in which certain chemicals are added to a mass finishing device (such as a vibratory bowl or tumbling barrel) in combination with

1 ceramic bodies (called "media") and one or more metal workpieces. The chemicals are  
2 mildly reactive to the metal, creating a soft coating (called "blackmode") on the surface,  
3 which is removed through vibratory agitation with the media. The resulting surface is  
4 smooth and shiny. The media employed in the '500 patent are abrasive – i.e., they are  
5 (compared to mildly or non-abrasive media) more rapidly degraded during the finishing  
6 process.

7 REM's U.S. Patent No. 4,818,333 discloses an improvement to the process of the  
8 '500 patent. That patent describes the use with chemicals of ceramic media having a  
9 density of at least 2.75 g/cc, and which are comparatively free of abrasive grit, as is  
10 commonly found in vibratory finishing media. Suitable media identified in that patent  
11 include ceramics of silica and alumina, in combination with other metal oxides. The  
12 claims of that patent characterize that media based upon the percentage of weight loss  
13 when employed in a vibratory finishing bowl under certain, specified conditions.

14 Neither REM patent identifies any improvement in the mechanical performance  
15 of articles finished using the disclosed processes. Nevertheless, REM has demonstrated  
16 that gears, bearings, and other articles processed in accordance with the '500 and '333  
17 patents can enjoy a significant enhancement in performance. And REM has used the  
18 processes of those patents commercially for that purpose. For example, U.S. Patent No.  
19 5,503,481 describes the use of the '333 patent process to give an isotropic surface on  
20 bearings, thereby imparting a greater fatigue life for those parts. However, the media  
21 employed in the '500 and '333 patents are not ideally suited for finishing processes aimed  
22 at enhanced mechanical performance. The '333 patent media have an average diamond  
23 pyramid hardness (DPH) value of at least 890, and therefore impart a mechanical texture  
24 to part surfaces that are exposed to it. Though the present invention is still applicable to  
25 cosmetic finishing, this invention addresses the problem of media hardness by using  
26 media (such as metals and/or plastic) that are softer, yet non-abrasive.

27 Softer non-abrasive media have been used commercially for the refinement of  
28 metal surfaces in the past. The ABRIL process, for example, has employed zinc media,  
29 but in combination with an abrasive compound.

30 REM has, more than a year before the filing of the present application, made  
31 commercial use of certain plastic abrasive media in combination with reactive chemicals

1 to finish brass and stainless steel parts. But those processes produced surfaces with an  $R_a$   
2 (6-10 microinches) that was insufficient for specular brightness or superfinishing.  
3 Through the processes disclosed herein, REM has been able to superfinish metal articles  
4 to a superior isotropic surface.

## 5 6 SUMMARY OF THE INVENTION

7 The invention includes a method that superfinishes metal surfaces to specular  
8 brightness and an isotropic finish. That method generally includes the step of placing an  
9 article(s) in a vibratory finishing bowl, in combination with a nonabrasive media and a  
10 chemical solution capable of reacting with the surface of said metal article to convert it to  
11 a softer form. These materials are then agitated for a time sufficient to impart the desired  
12 surface to the article. In one embodiment of that invention, the non-abrasive media is a  
13 plastic media. In another embodiment, the media is metal. Preferably, the media are not  
14 significantly reactive with the chemical solution.

15 The use of metal or plastic media offers several advantages over the processes  
16 disclosed in the '500, 481' and '333 patents. As noted above, those media are softer, and  
17 therefore less prone to mechanical texturing of the processed surface. Moreover, plastic  
18 and metallic materials are more easily formed (as compared to ceramics) into specific  
19 shapes and sizes – which is important in finishing parts of varying shape and dimension.  
20 The process of this invention is illustrated in the multiple examples that follow. Those  
21 examples illustrate other embodiments of the invention – specifically, the articles  
22 processed using the methods disclosed herein.

## 23 24 DEFINITIONS

25 The following definitions are employed to describe and/or claim the invention:

26 “ $R_a$ ” (or Arithmetic Mean Roughness) is defined and measured in accordance  
27 with ISO standard 4287, which is the same as DIN standard 4768.

28  $R_{max}$  (or Maximum Roughness Depth), is defined and measured in accordance  
29 with DIN standard 4768.

30 A “superfinished surface” is one that has an  $R_a$  of less than or equal to 2.5  
31 microinches.

1 An "isotropic surface" is one having substantially no orientation to its surface  
2 irregularities.

3 "Media" are solid bodies placed in a vibratory finishing bowl, other than the  
4 articles to be finished.

5 "Specular brightness" is the property of a surface in which you can see a clear  
6 reflection of an object.

7 "Non-abrasive" media are media that, under the intended set of processing  
8 conditions, will lose less than 0.1% of their weight per hour, and achieves the defined  
9 superfinished surface condition.

### 11 BRIEF DESCRIPTION OF THE DRAWING

12 Figure 1 are SEM images of the surface of a 4140 steel coupon with an HRC of  
13 approximately 43-45 finished using REM's '333 patent process (1(a)), and the process of  
14 the present invention as practiced with plastic media (1(b)) and stainless steel media  
15 (1(c)).

### 17 DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

18 This invention provides a method for producing on metal articles superfinished,  
19 isotropic surfaces with specular brightness. The metal articles are machined through  
20 conventional methods that are well known in the art. As a typical final fabrication step,  
21 the article is superfinished to an isotropic finish with specular brightness. A procedure  
22 for doing that is described below:

#### 23 Finishing Procedure

24 A superfinished, isotropic surface can be applied to a metal article through a  
25 significant and novel modification of the processes disclosed in U.S. Patent Nos.  
26 4,818,333, 4,491,500, and 5,503,481.

#### 27 a. The Vibratory Bowl

28 Isotropic surfaces may be achieved using a conventional vibratory finishing unit,  
29 of the sort described in the 5,503,481, '500 and '333 patents. The unit may be operated  
30 at 800-1500 revolutions per minute, at an amplitude of 1 to 8 millimeters. The '333  
31 patent identifies a 2-4 millimeter amplitude as preferred. During operation, the chemical

1 solution may be added on a flow-through basis, such that fresh solution is continuously  
2 introduced and used solution is continuously drawn off and discarded. That solution may  
3 be introduced at a rate of 0.25-0.4 gallons per hour per cubic foot. Operation of the  
4 equipment will generate heat that typically increases the temperature of the vibratory  
5 system (media, solution and parts) to about 35 degrees Centigrade over time.

6 b. The Media

7 This invention achieves improved metal finishing results (over the methods  
8 described in REM's '333, '500 and '481 patents) by employing different media and  
9 chemical treatments that are compatible with those media. In one embodiment, the media  
10 are composed of a plastic that is non-abrasive under the operating conditions of the  
11 vibratory bowl. Those media preferably have a hardness of approximately 57 on the  
12 Barcol scale, and are "soft" as compared to the ceramic media disclosed in REM's '333  
13 patent. Under the chemical treatment conditions disclosed below, these soft, plastic  
14 media give better surface treatment than has been achieved using the ceramic media of  
15 REM's '333 patent. One example of a suitable (and commercially available) plastic  
16 media is the TROWALPLAST PP product sold by Walther Trowal, Ltd. That media is  
17 composed of 50% (by weight) alumina bonded with an unsaturated polyester resin. It has  
18 a density of about 1.8 g/cm<sup>3</sup> and a crystal size of less than 0.9 mm.

19 In another embodiment of this invention, the media are composed of a metal that  
20 is inert to the chemical treatment conditions. One such material that is compatible with  
21 the chemical treatments disclosed below is AISI grade 302 stainless steel. Those media  
22 are available from various suppliers in a variety of shapes and sizes. Abbott Ball is one  
23 supplier of such media. When using these media, it may be necessary to employ vibratory  
24 bowls having a greater mass carrying capacity.

25 c. The Chemical Solution

26 The chemical solutions useful in this invention are described generally in REM's  
27 '500 and '333 patents. The chemical solution reacts with the metal of the treated articles,  
28 leaving a soft coating of reaction product on the surface ("blackmode"). The reactive  
29 chemicals employed in these solutions may include phosphoric acid or phosphates,  
30 sulfamic acid, oxalic acid or oxalates, sulfuric acid or sulfates, chromic acid or  
31 chromates, bicarbonate, fatty acids or fatty acid salts, or mixtures of these materials. The

1 solution may also contain an activator or accelerator, such as zinc, magnesium, iron  
2 phosphates and the like, as well as inorganic or organic oxidizers, such as peroxides,  
3 meta-nitrobenzene, chlorate, chlorite, persulfates, nitrate, and nitrite compounds.

4 A variety of chemical solutions useful in this invention are sold commercially by  
5 REM Chemicals, Inc. These solutions include acid/salt components in a weight percent  
6 range of approximately 15-45%, promoters in a range of 1% by weight, and oxidizers in a  
7 range of 0 to 15% by weight. Specific formulations that may be used in this invention  
8 include the following REM products:

- 9 1. FERROMIL<sup>®</sup> FML 575 IFP, an acidic aqueous solution which contains a  
10 mixture of inorganic phosphates with a proprietary oxidizer and surfactant.
- 11 2. FERROMIL<sup>®</sup> VII AERO-700, an aqueous organic acid solution with a  
12 proprietary surfactant and inhibitor.
- 13 3. REM<sup>®</sup> COPPERMIL 7 an acidic aqueous solution which contains  
14 hydrogen peroxide and a proprietary inhibitor.

15 These formulations are sold as a concentrate, which can be diluted with water to prepare  
16 the chemical solution that is introduced to the bowl. Typical dilutions will introduce the  
17 concentrate as 5-80% by volume of the solution.

18 Following this treatment, it is often desirable to introduce a second solution into  
19 the vibratory bowl to burnish the metal articles. One suitable burnishing solution for  
20 steel is sold by REM Chemicals, Inc. under the label FERROMIL<sup>®</sup> FBC-218. That  
21 solution contains a complex inorganic phosphate and a proprietary surfactant. REM<sup>®</sup>  
22 COPPERMIL CBC-235 burnish is sold by REM Chemicals, Inc. and is suitable for brass.  
23 It is an aqueous phosphoric acid based product that also contains proprietary surfactants  
24 and inhibitors.

25 This invention provides an isotropic surface by balancing the rates of blackmode  
26 formation and removal. If the blackmode is too hard, then there will not be enough  
27 energy to remove it, and effective refinement stops. If the blackmode is too soft, then the  
28 process will produce a surface that is textured. Blackmode characteristics are also  
29 important to achieving a uniform finish that will leave the parts in tolerance once the  
30 process is complete. Provided below are multiple examples of process conditions that  
31 achieve that balance.

1 The following are worked examples of the present invention, as compared to the  
2 process disclosed in REM's '333 patent:

3 Example 1 (Comparison)

4 An SAE 4140 steel coupon, HRC 43-45, and an adjustable wrench, HRC 42-45,  
5 are finished in accordance with the process disclosed in REM's '333 patent.

6 A ten cubic foot Sweco vibratory bowl is used, at a lead angle of 60 degrees with  
7 a vibration amplitude of 4.0 mm. The media are FERROMIL<sup>®</sup> Media #9 (available  
8 through REM), the composition of which are disclosed as "Media C" in REM's '333  
9 patent. Those media are used as ¾ inch cones. The chemical solution is FERROMIL<sup>®</sup>  
10 FML-575 IFP, described above, which is maintained at 12.5% by volume for 6.75 hours  
11 at a flow rate of 3.75 gallons/hour. The parts are subsequently burnished through the  
12 introduction of FERROMIL<sup>®</sup> FBC-218 solution (described above) maintained at 1% by  
13 volume, and flowed at 24 gallons/hour for a 4-hour period. The bowl is loaded with 20  
14 square feet of 4140 steel bar HRC 43-45.

15 The steel coupon has a starting  $R_a$  of 23.4 (microinches as all  $R_a$  and  $R_{max}$  values  
16 stated herein) and a starting  $R_{max}$  of 200, as measured using a profilometer. After  
17 processing, the coupon has an  $R_a$  of 1.46 and  $R_{max}$  of 13.7, and a medium specular bright  
18 appearance. Figure 1(a) shows that FERROMIL<sup>®</sup> Media #9 results in a highly textured  
19 final surface finish on a 4140 steel coupon with a 43-45 HRC.

20 The adjustable wrench does not appear fully finished having residual blackmode  
21 in and around the lettering, along the shoulder area of the handle, and running along the  
22 length of the handle. The roughness measurements were made using a Model MP4i  
23 Perthometer manufactured by Mahr, along a trace length of 0.06 in. with a Gaussian  
24 filter.

25 Example 2 – Finishing With Plastic Media

26 An SAE 4140, 43-45 HRC, steel coupon and an adjustable wrench, 42-45 HRC,  
27 are finished in accordance with one embodiment of this invention.

28 A ten cubic foot Sweco vibratory bowl is used, at a lead angle of 60 degrees with  
29 a vibration amplitude of 4.0 mm. The media are Walther Trowal TROWALPLAST PP  
30 media, which are described above. Those media are used as 19-mm cones. The chemical  
31 solution is FERROMIL<sup>®</sup> FML-575 IFP, described above, which is maintained at 12.5%

by volume for 6.75 hours at a flow rate of 3.75 gallons/hour. The parts are subsequently burnished through the introduction of FERROMIL<sup>®</sup> FBC-218 solution (described above) maintained at 1% by volume, and flowed at 24 gallons/hour for a 4-hour period. The bowl is loaded with 20 square feet of 4140 steel bar HRC 43-45.

The steel coupon has a starting  $R_a$  of 20.3 and a starting  $R_{max}$  of 230, as measured using a profilometer. After processing, the coupon has an  $R_a$  of 0.49 and  $R_{max}$  of 7.32. In final appearance, the coupon is of superior specular brightness, i.e., the surface is as reflective as a mirror. Figure 1(b) shows that TROWALPLAST PP media results in a significantly superior surface finish on the 4140 steel coupon with a 43-45 HRC in comparison with Figure 1(a) produced using the FERROMIL<sup>®</sup> Media #9.

The adjustable wrench also had a finish better than what was obtained in example 1. There is no residual blackmode buildup on the shoulder of the handle or in the raised lettering. The finish is superior to that obtained using the '333 patent procedure (example 1).

### Example 3 – Finishing With Stainless Steel Media

An 8620 case hardened coupon and gear are finished in accordance with another embodiment of this invention.

A four cubic foot Vibra Finish of Canada vibratory bowl is used, at a lead angle of 60 degrees with a vibrational amplitude of 4.5 mm. The media are 302 stainless steel, introduced as a mixture of 20 w/w% 3/32" X 3/8" pins; 40 w/w% 1/8" diagonals; 40 w/w% 3/16" ballcones. The chemical solution is FERROMIL<sup>®</sup> VII AERO-700 described above, which is maintained at 75% by volume for 8.0 hours at a flow rate of 2.5 gallons/hour. The parts are subsequently burnished through the introduction of FERROMIL<sup>®</sup> FBC-218 solution (described above) maintained at 1% by volume, and flowed at 20 gallons/hour for a 4-hour period. For this example, the bowl is loaded with 20 square feet of 8620 steel bar HRC 58-60. The gear (Webster 8620 carburized steel, 20-tooth gear, 8-diametral pitch and 25° pressure angle) has a fillet radius of approximately 0.0469 inches.

The steel coupon has a starting  $R_a$  of 29.8 and a starting  $R_{max}$  of 262, as measured using a profilometer. After processing, the coupons have an  $R_a$  of 1.95 and  $R_{max}$  of 24.4. In final appearance, the coupon is of medium specular brightness in appearance.

The side surface of the gear tooth had a starting  $R_a$  of 41.0 and starting  $R_{max}$  of 202. After processing, that surface had an  $R_a$  of 1.83 and  $R_{max}$  of 18.4. The gear tooth working surface had a starting  $R_a$  of 10.6 and starting  $R_{max}$  of 94.4. After processing, that surface had an  $R_a$  of 3.9 and  $R_{max}$  of 31.4. Because this was an off-the-shelf OEM automotive gear, it was not of sufficient quality to produce a superfinish on its working surfaces. However, even the root fillet recesses of the gear showed significant surface finishing. There was no blackmode in the recessed areas. Although parts were slightly discolored after burnishing, they did have a specular appearance.

A SAE 4140 steel coupon and with a 43-45 HRC has a starting  $R_a$  of 23.7 and a starting  $R_{max}$  of 242, as measured using a profilometer. After processing, the coupon has an  $R_a$  of 1.46 and  $R_{max}$  of 12.0. Figure 1(c) shows that 302 stainless steel media results in a significantly improved surface finish on the 4140 steel coupon (FERROMIL® VII AERO-700 under similar conditions as above) in comparison with Figure 1(a) produced using the FERROMIL® Media #9. It is not quite as good though as that produced by the TROWALPLAST PP media.

#### Example 4 – Finishing a Delicate Brass Part with Plastic Media

A delicate thin walled brass cigarette lighter case is finished in accordance with one embodiment of this invention.

A 0.75 cubic foot Raytech vibratory bowl is used, at 25% power through a variable power rheostat. The media are Walther Trowal TROWALPLAST PP media, which are described above. Those media are used as 19-mm cones. The chemical solution is REM® COPPERMIL 7 described above, which is maintained at 10% by volume for 5 hours at a flow rate of 0.3 gallons/hour. The parts are subsequently burnished through the introduction of REM® COPPERMIL CBC-235 solution (described above) maintained at 1% by volume, and flowed at 3 gallons/hour for a 1 hour period. The bowl is loaded with 1.3 square feet of C36000 brass bar.

The lighter has a starting  $R_a$  of 10.7 and a starting  $R_{max}$  of 77.6, as measured using a profilometer. After processing, the lighter has an  $R_a$  of 1.22 and  $R_{max}$  of 13.4. In final appearance, the lighter is of superior specular brightness.